Development of Liquid-Fueled Portable Military Power Systems at Battelle

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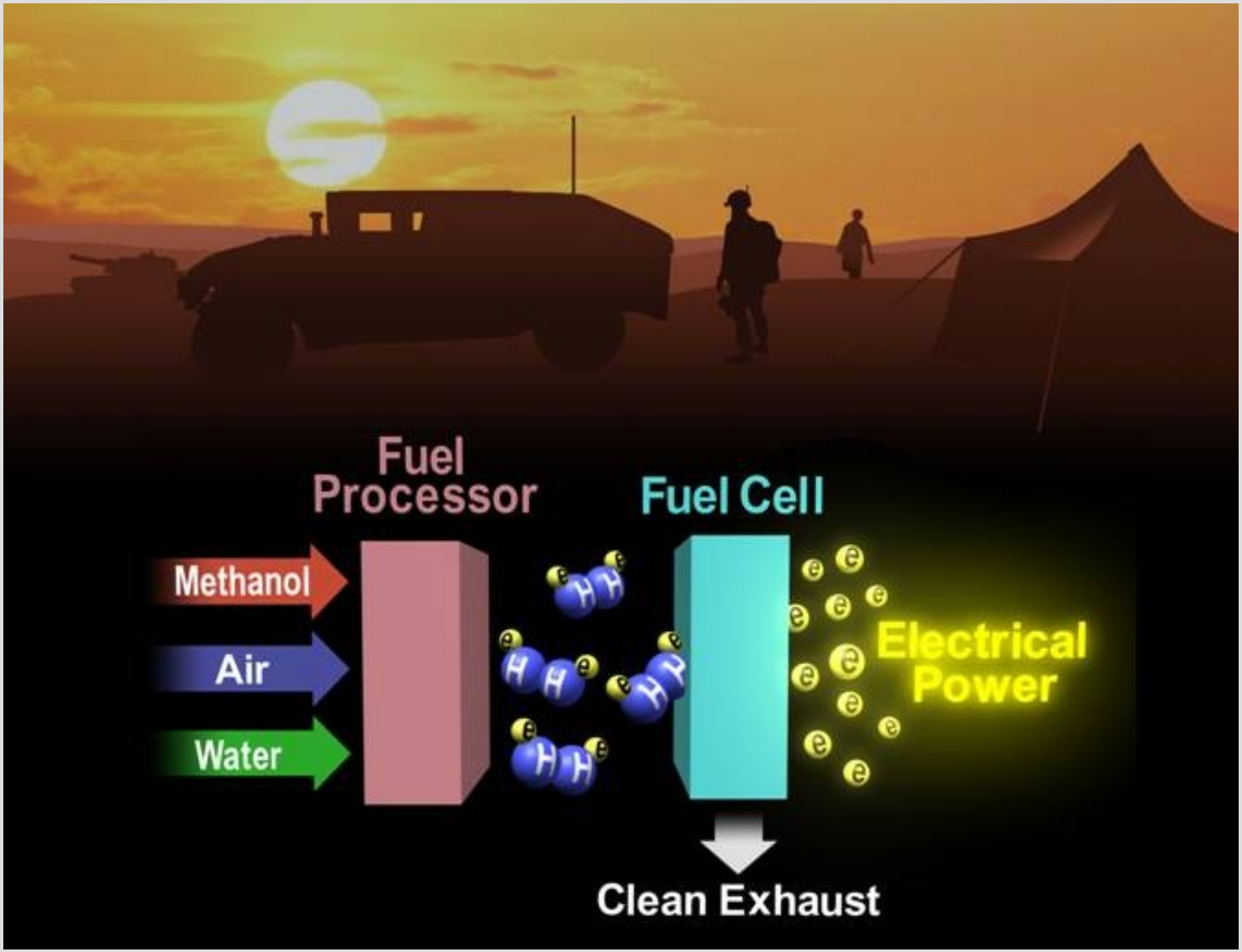
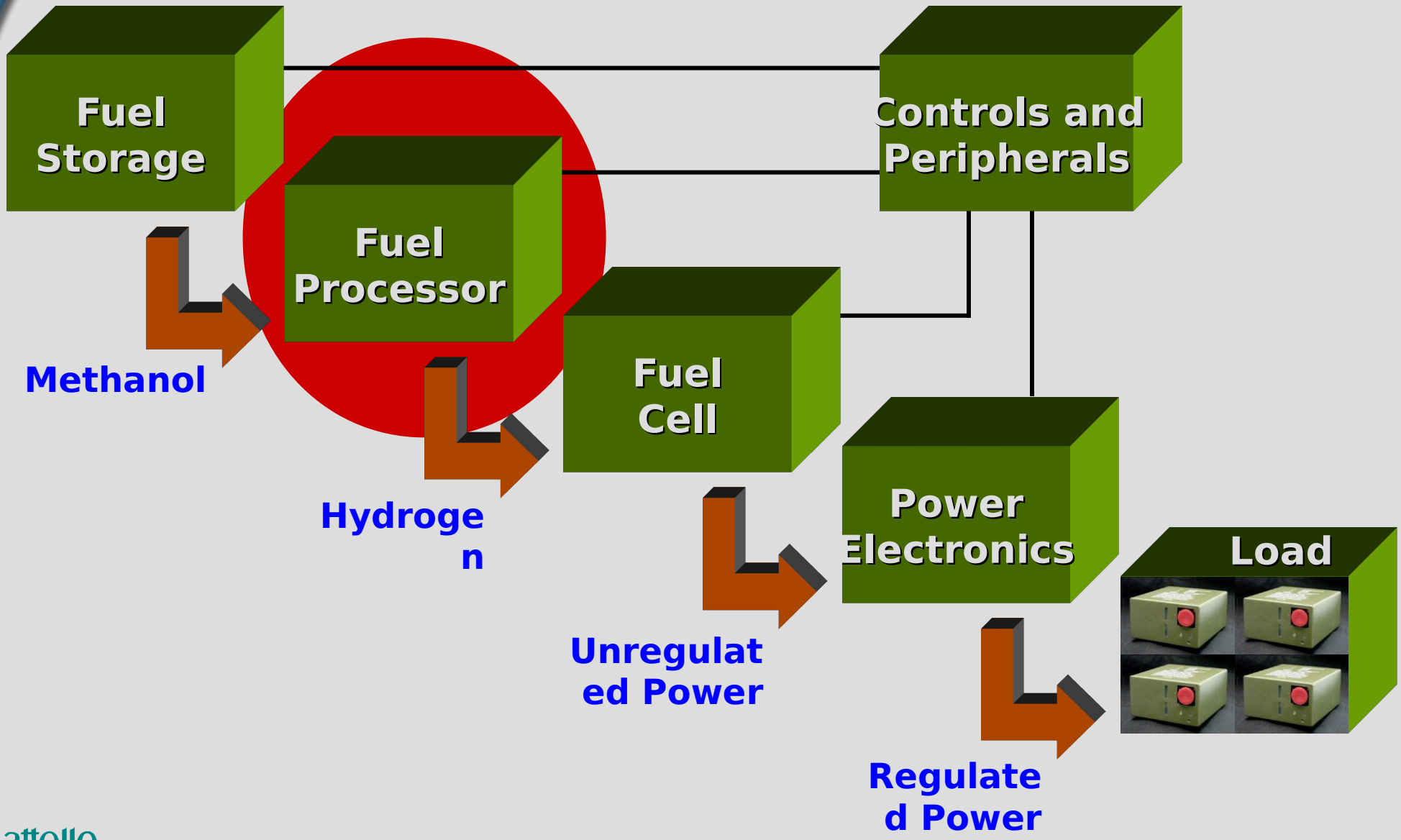
Battelle

Pacific Northwest Division

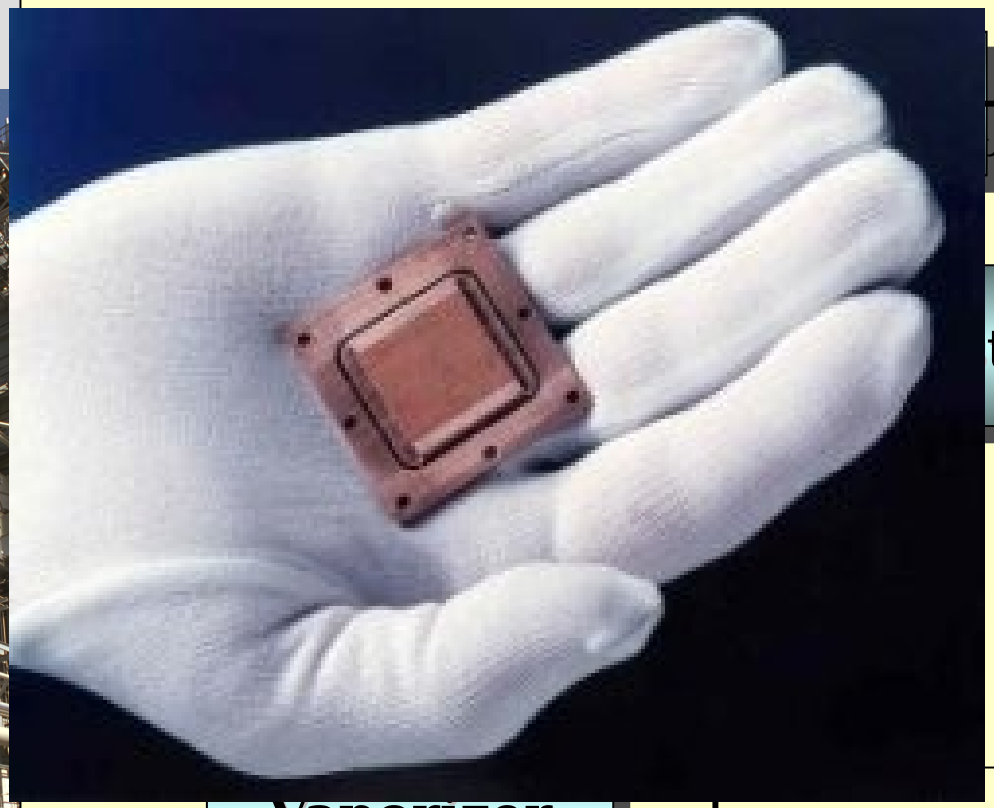
Overall System



Portable Power System Components



Hydrogen Production



Power

Fuel Cell

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Air

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Vaporizer

Fu

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Water

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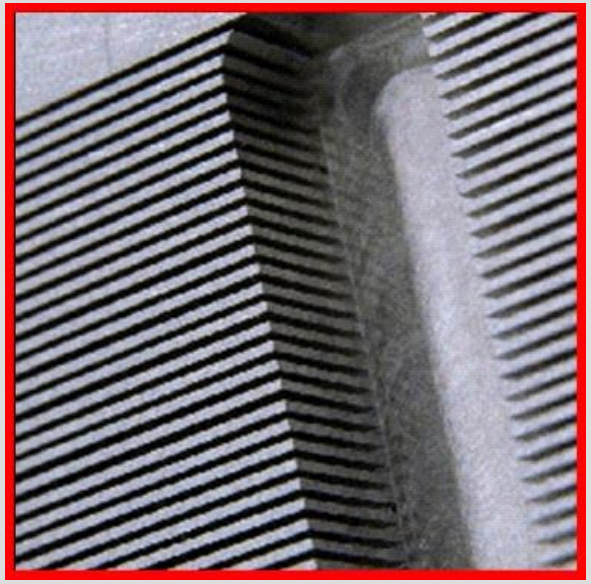
Microchannels and Advanced Catalysts



- Micron-scale dimensions
- **Rapid heat & mass transfer**
- Laminate fabrication
- Integrated monolith supports
- Porous substrates
- **Highly active catalysts**
- Low pressure drop

- **Process intensification**

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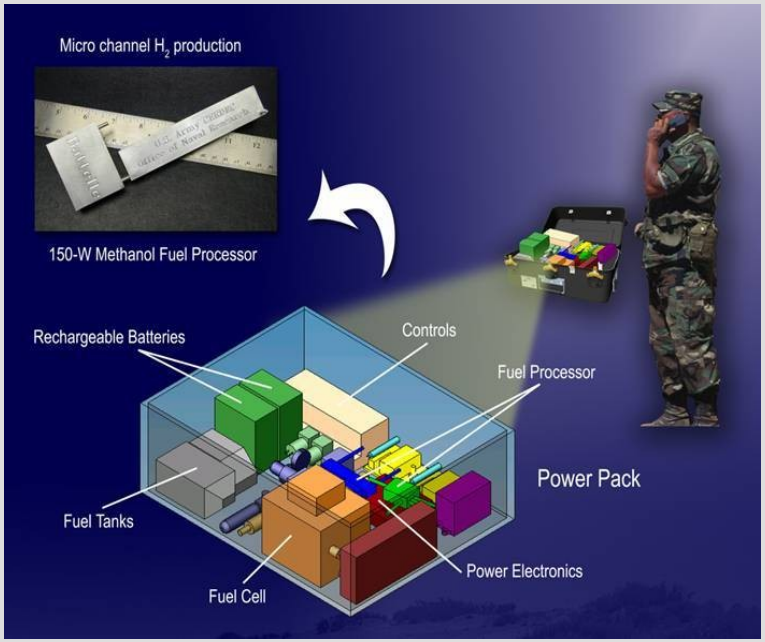
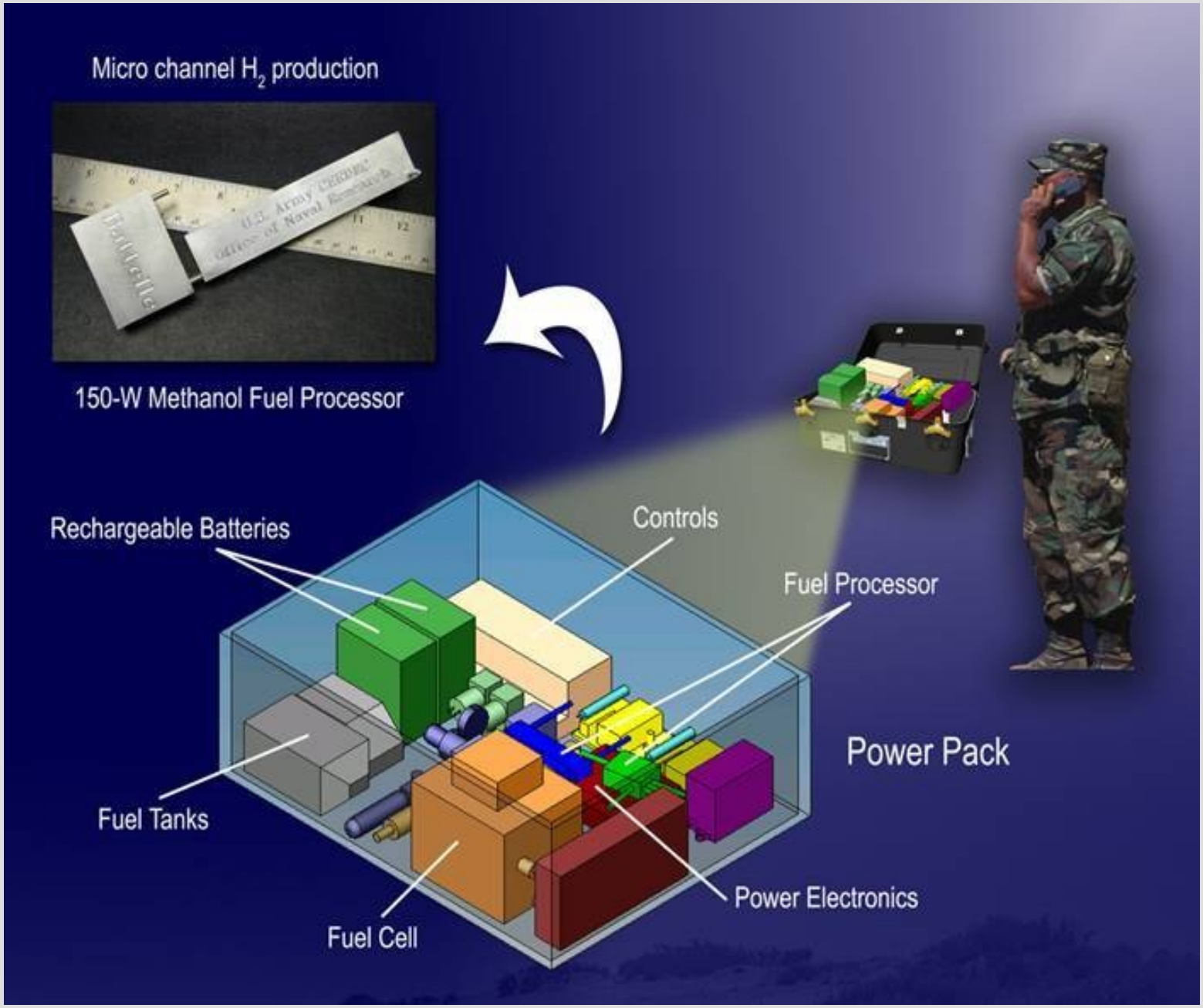
Soldier Power Options

- Squad charger or small APU
  - 250 to 500 watts
  - <20 L, <10 kg
  - Battery charging, base power
  - Packaged fuel or logistic fuel



- Soldier-Portable Hybrid Power
  - 10 to 50 watts
  - <1 L, <1.0 kg
  - Fuel cell – battery hybrid
  - Packaged fuel

Squad Charger Concept



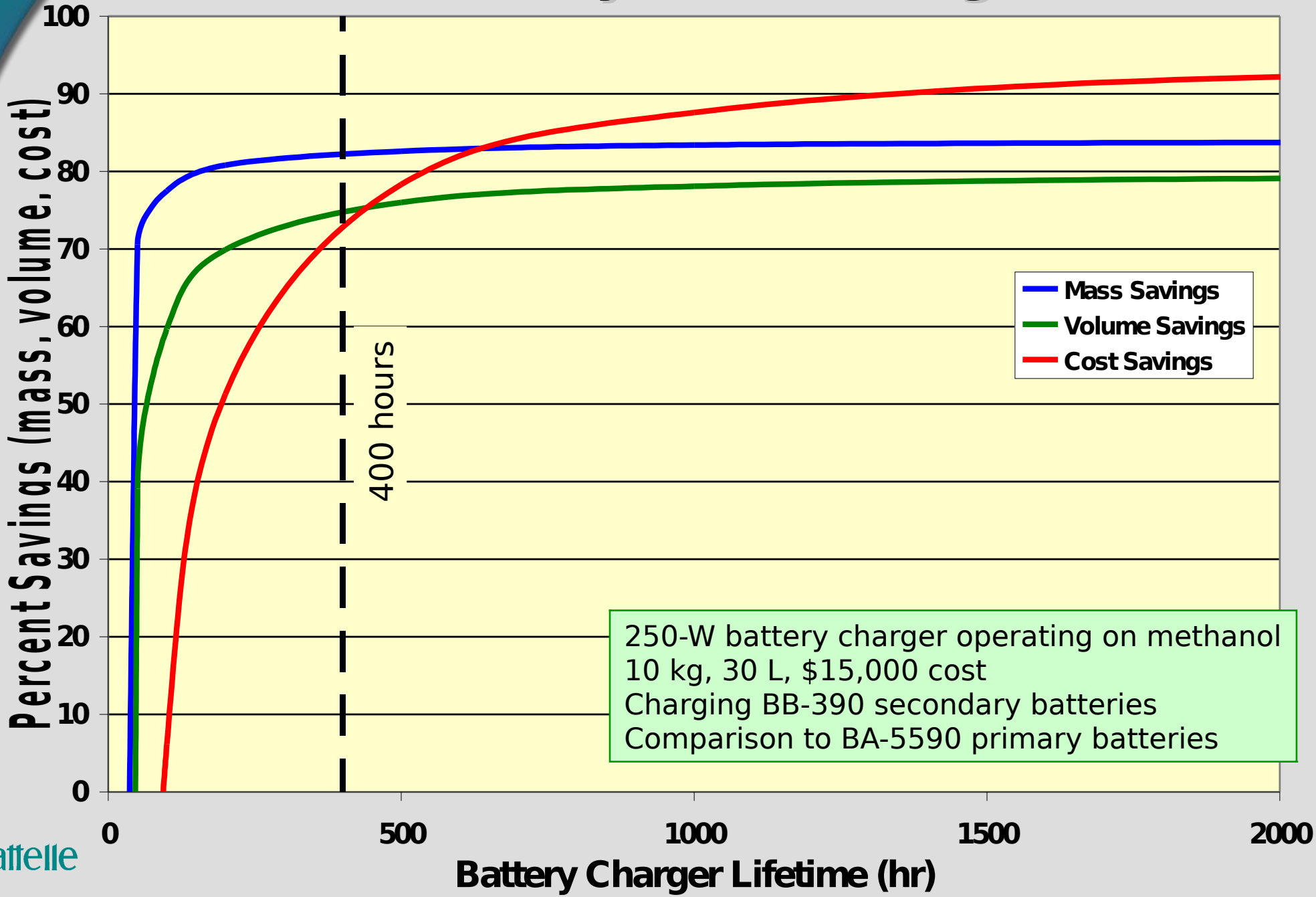
Squad Charger: Potential Savings @ 1000-hr Lifetime

	Total Mass (kg)	Total Volume (L)	Batteries Used	Total Cost ($)	Energy Cost ($/Whr)
Primary Batteries	1700	1485	1668	167,000	0.67
Secondary Batteries with Portable Charger	283	325	22	20,630	0.083
Percent Decrease	**83%**	**78%**	**99%**	**88%**	**88%**

Calculations based on the following assumptions:

- Battery charger hardware: 250 W, 1000-hr. life, 10 kg, 30 L, $15,000 ea.
- Battery charger fuel (methanol/water): $0.62/gal., 130 mL/battery charge
- Primary battery BA-5590: 0.89 L, 1.02 kg, $100 ea., 150 Whr.
- Secondary battery BB-390: 0.89 L, 1.7 kg, $254 ea., 118 Whr.

Primary Batteries versus Secondary-with-Charger



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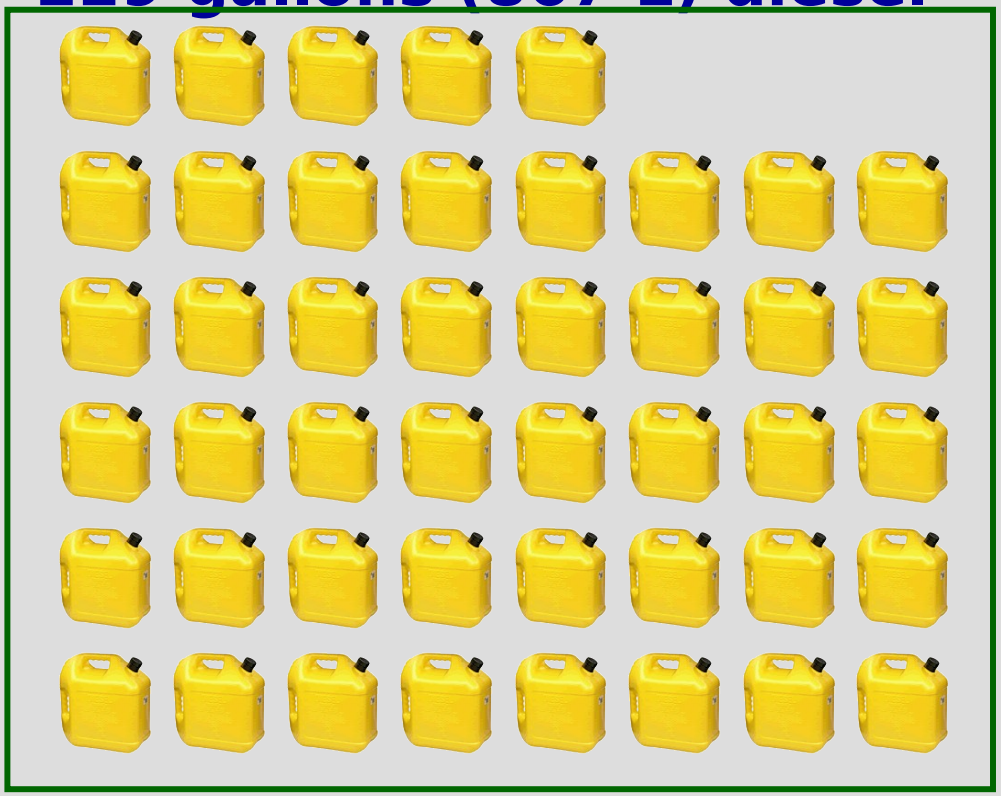
Potential Savings
336 Hours (14 Days) at 900 W

Idling HMMWV @ 900 W

229 gallons (867 L) diesel

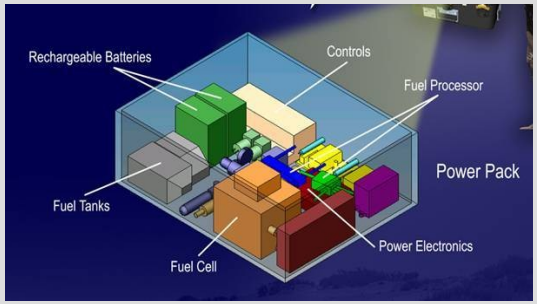


Methanol battery charger scaled to 900 W

48.4 gallons (183 L) methanol

(~80% reduction)

Each container represents 5 gallons of fuel



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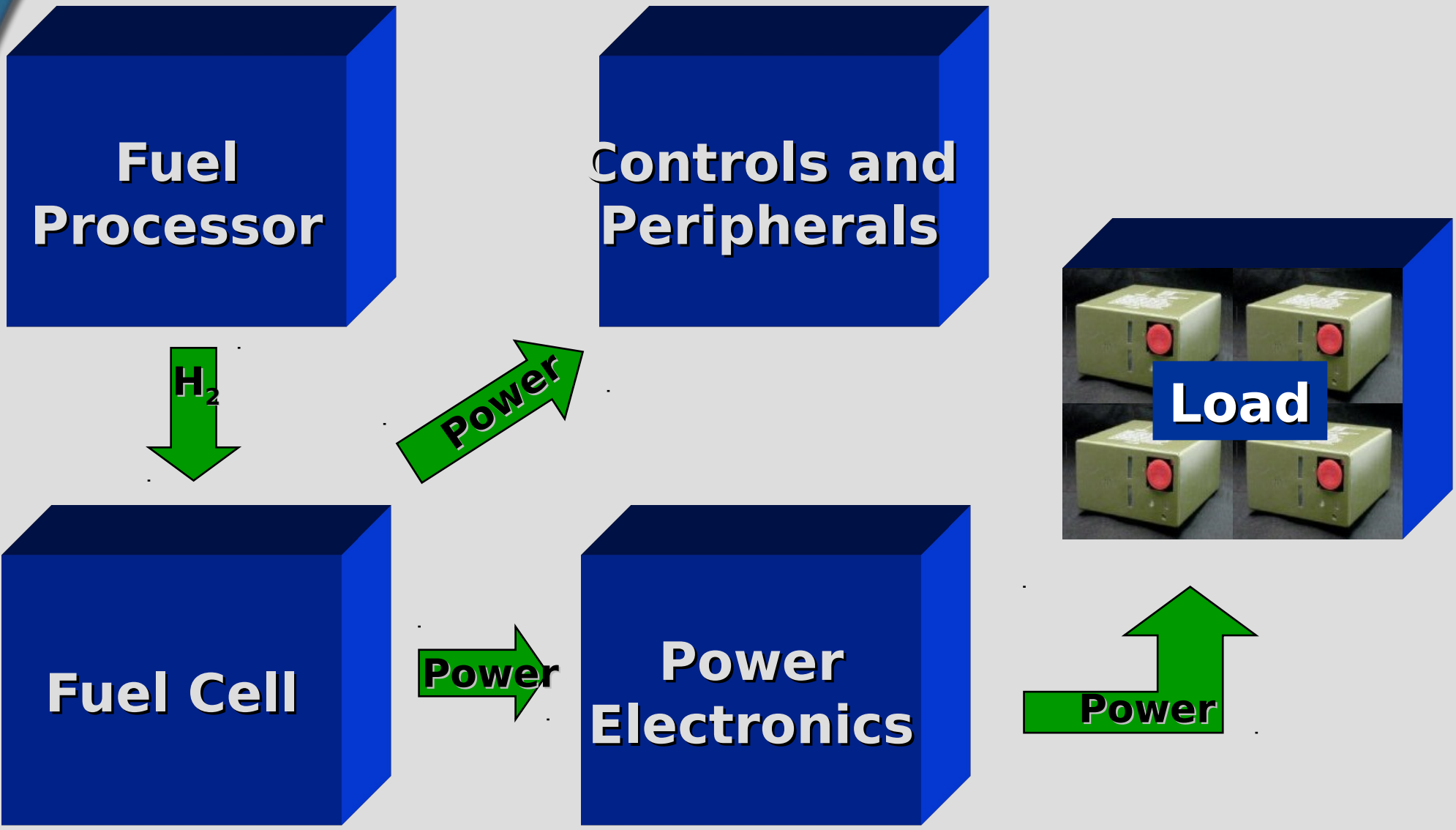
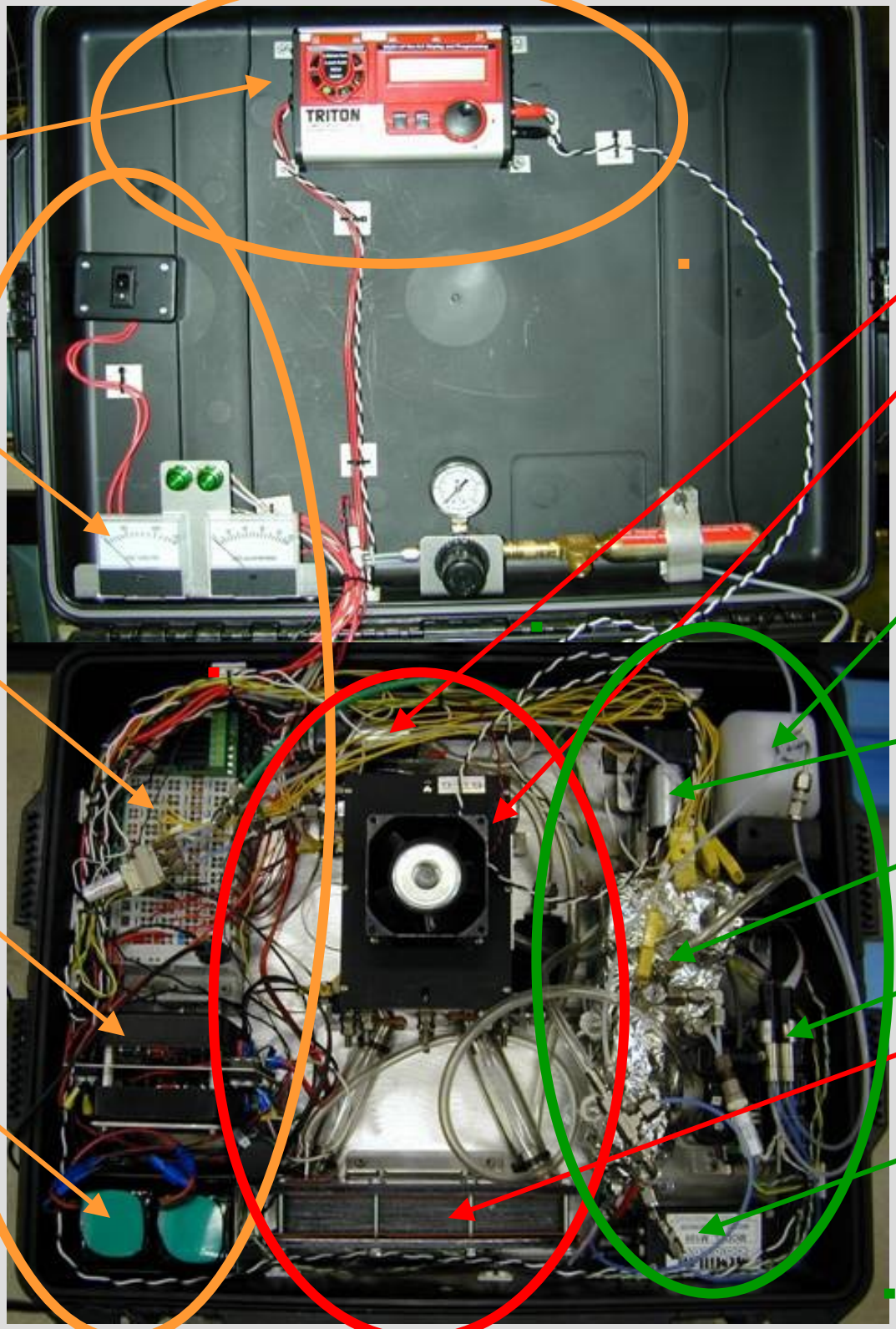
System Overview



TRL ~4.5-5 Demonstration System



Battery Charger

Power Indicators

Control Electronics

Power Electronics

Startup Battery

FC Air Pumps

Fuel Cell

Fuel Tanks

FP Air Pumps

Fuel Processor

FP Liquid Pumps

FC Humidifier

FP Liquid Flow Meter

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Complete Methanol Fuel Processor

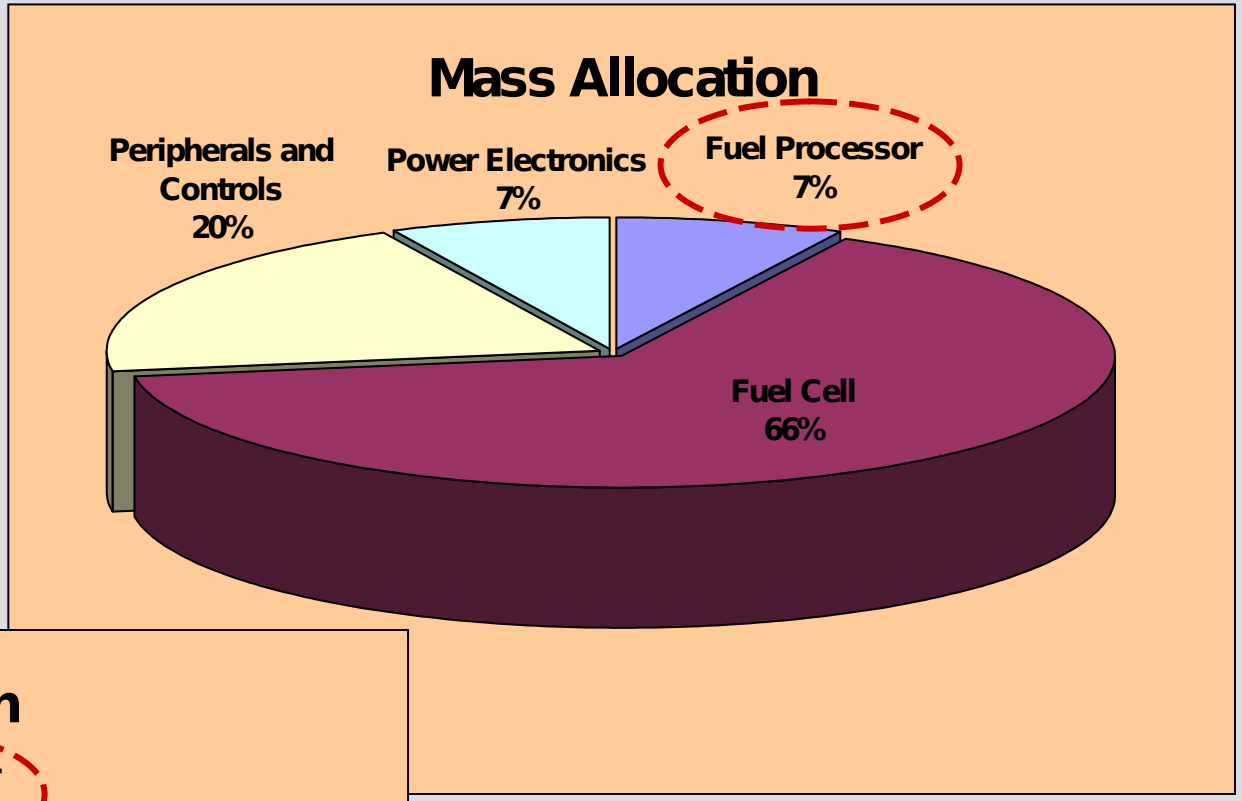
Power Output	60-180 W_e
Volume	160 cm^3
Mass	480 g
Thermal Efficiency	56-70+ %
H_2	

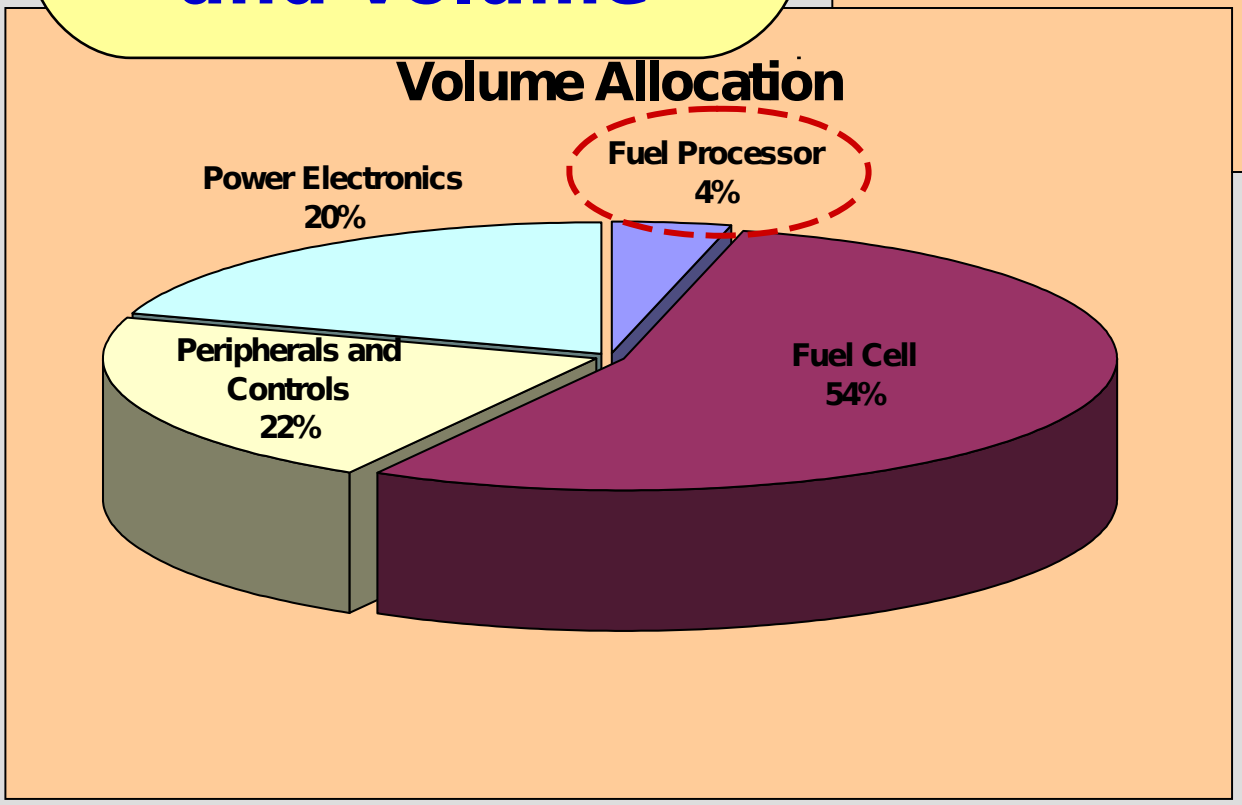
Power System Characteristics
Operating at 100 W_e net output

	Phase I Values	Phase II Projections
Energy density of system (14 days)	780 Whr/kg	1300 Whr/kg
Energy density, fuel only	1380 Whr/kg	1700 Whr/kg
System mass	8 kg	7 kg
System volume	6 L	4 L
System Setup	No recycle streams, large parasitic losses	Anode gas combustion, system water recycle

Relative Mass and Volume

Fuel cell currently accounts for majority of system mass and volume





Hybrid Soldier Power

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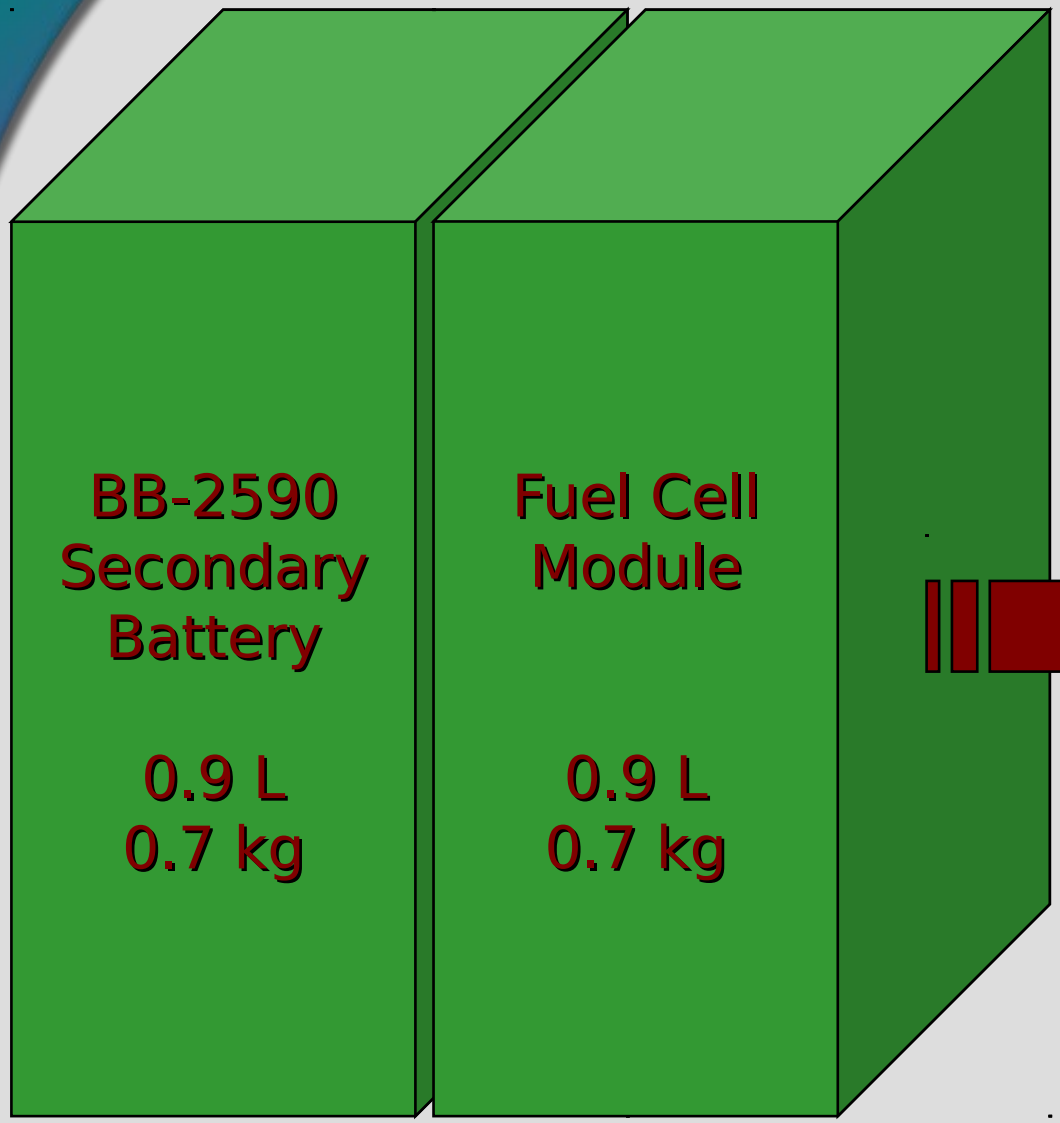
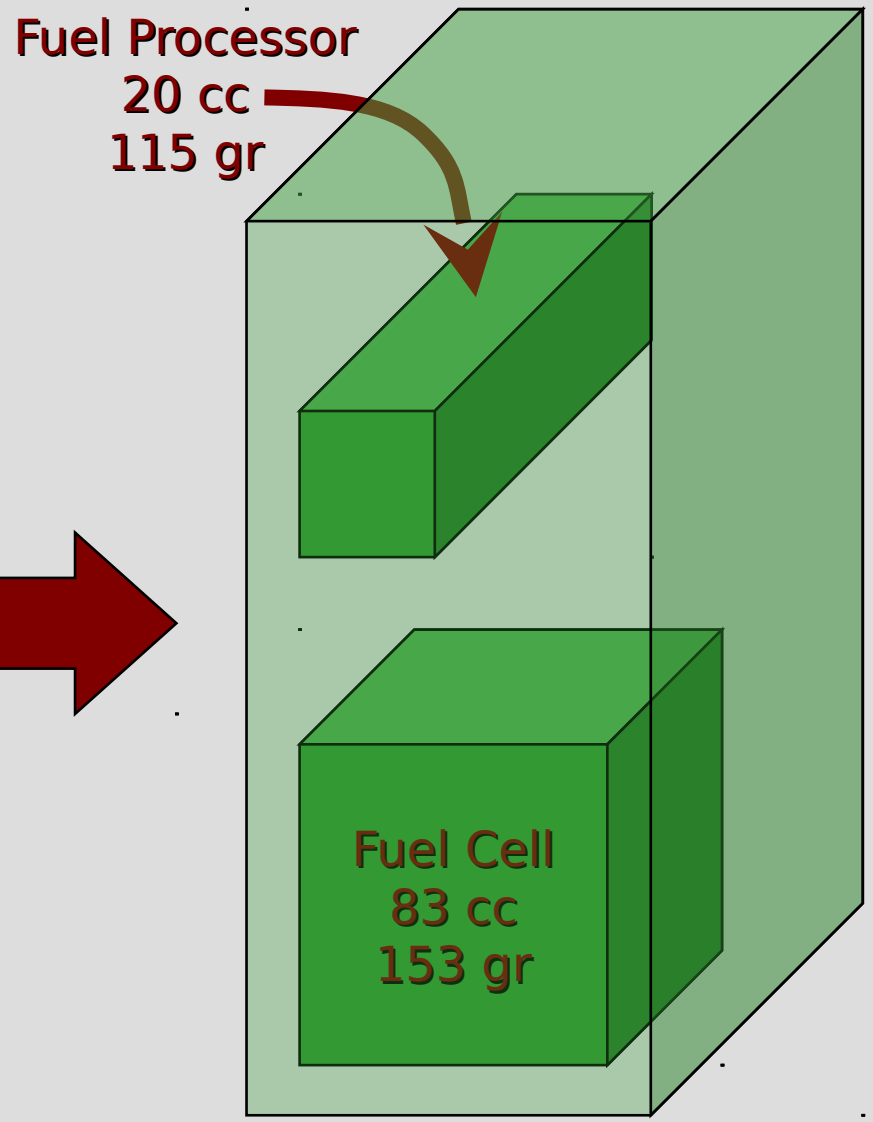
Hybrid System Constraints



Proposed Hybrid Power System



Fuel Cell Portion of Syster

Hybrid Power: Potential Savings @ 2000-hr Lifetime 12-W System

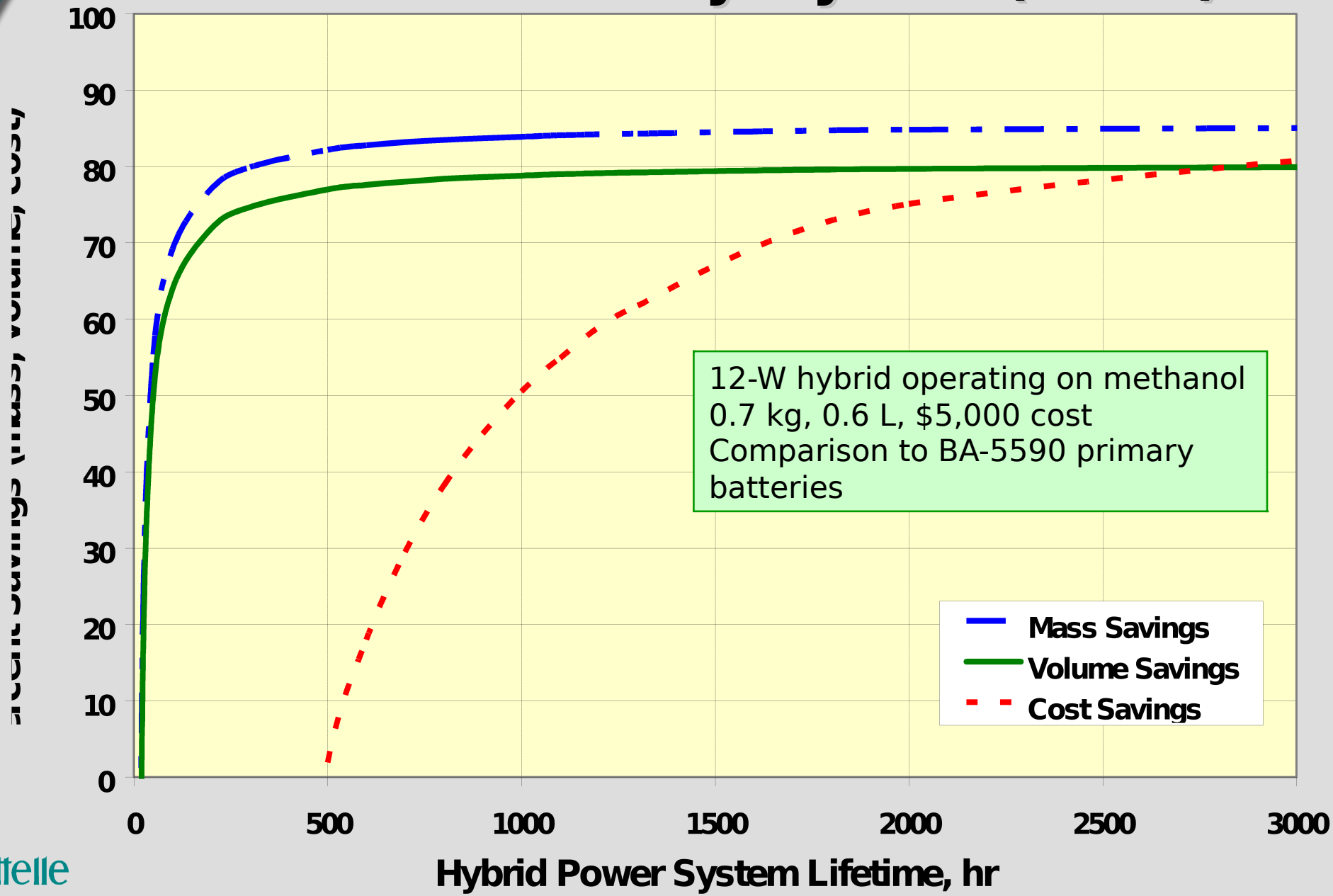
	Total Mass (kg)	Total Volume (L)	Batteries Used	Total Cost ($)	Energy Cost ($/Whr)
Primary Batteries	205	179	200	20,100	0.67
Portable Power Supply	31	36	1	5006	0.17
Percent Decrease	**85%**	**80%**	**99.5%**	**75%**	**75%**

Calculations based on the following assumptions:

Power supply hardware: 12 W_e, 2000 hr life, 0.68 kg, 0.63 L, $5,000 ea.

Power supply fuel (methanol/water): $0.62/gal., 1.15 mL/Whr, 0.97 g/Whr

Primary Batteries versus Fuel Cell Battery Hybrid (12 W)



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Soldier Power Status

- 20-W methanol reformer demonstrated
- CO cleanup under development/integration
- D[illegible]with fu[illegible]ly 2005

Methanol Steam Reformer	
Design Power	20 W
Construction	Stainless steel
Mass	~90 grams
Volume	~15 cm^3
Demonstrated Power	6-34 W_e
Operating Temperature	350-360 ˚C
Thermal	38-63 %

Contributors

- Project Management
  - Chip Larson, Daniel Palo
- Fuel Processor
  - Daniel Palo, Jamie Holladay, Bob Rozmiarek, Benjamin Roberts
- Fuel Cell
  - Jamie Holladay, Vilayanur Viswanathan
- Controls and Electronics
  - Matthew Donnelly, Paul Boyd, Darrel Hatley
- Peripherals
  - Claus Danielson, Jamie Holladay
- Catalyst Development
  - Robert Dagle, Gordon Xia, Cathy Chin, Yong Wang, John Hu

Acknowledgements

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Office of Naval Research

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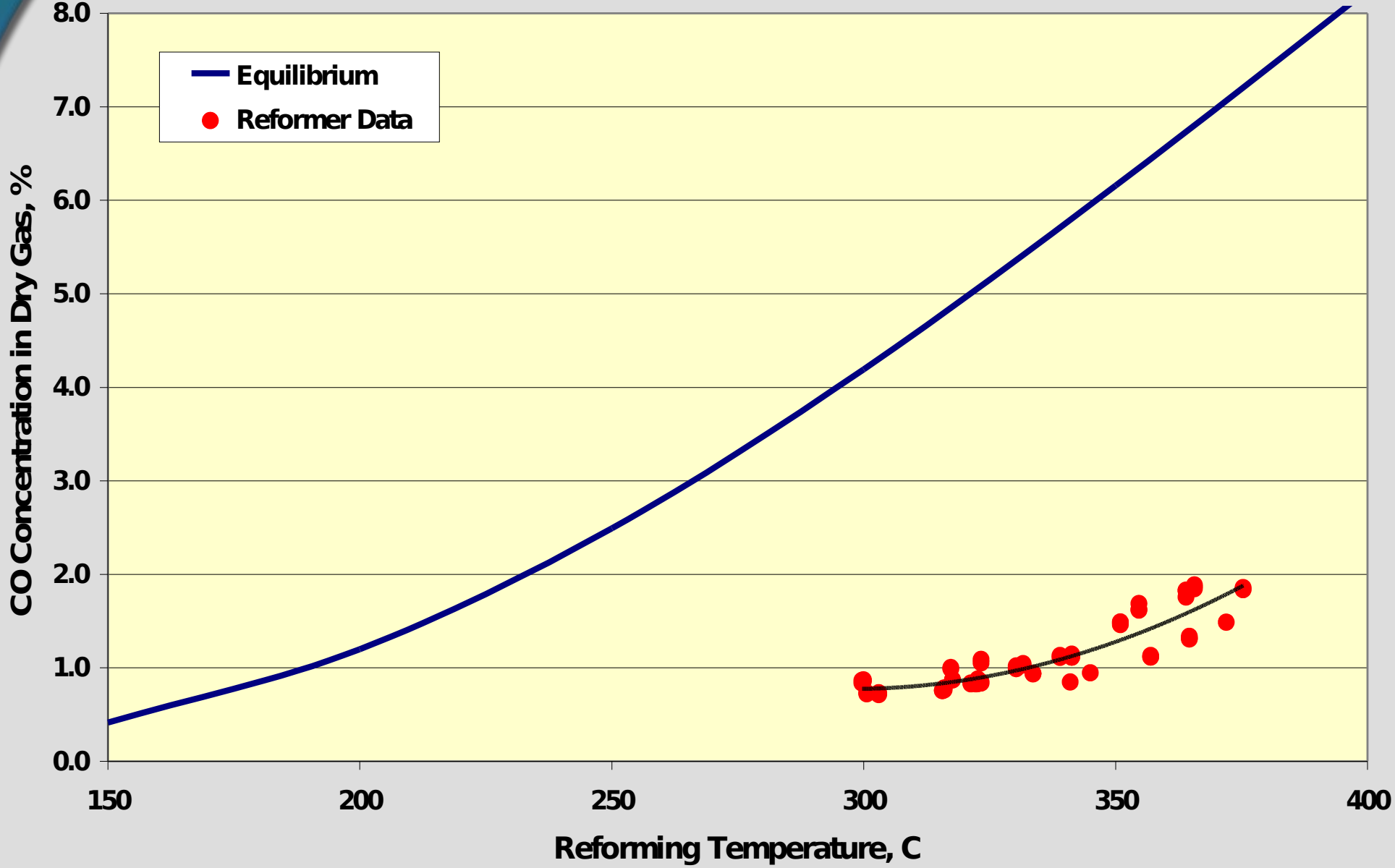
Backup Slides

Accomplishments

- Compact Methanol Fuel Processor
  - High efficiency
  - “Clean” hydrogen output
  - Consistent performance
  - Long catalyst life (> 1000 hr)
- Major System Components
  - Fuel cells acquired and demonstrated with reformate
  - Balance-of-plant components incorporated
  - Integrated control system developed
- **System Demonstration**
  - **Fuel processor, fuel cell, and balance-of-plant**
- **Remaining hurdles are “engineering” related**

CO Concentration vs Equilibrium

Equilibrium prediction and reformer data for methanol steam reforming
H_2O/MeOH = 1.2, methanol conversion >95%



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Microchannel Steam Reformer Properties

Material	**316 stainless steel**
Fabrication Method	**Diffusion bonding, brazing, and welding**
Unit operations	**Catalytic steam reforming, catalytic combustion, vaporization (2), heat recuperation (2)**
Combustor feed stream	**Methanol and air**
Reformer feed stream	**Methanol/water premix (60 wt% methanol, 1.2:1 steam to carbon ratio)**
Operating temperature	**300-350 ˚C**
Reformate	**~71% H_2, ~24% CO_2, ~4.8% H_2O, ~0.8%**

Integrated Methanol Reformers

Design Power, W_e [α]	**20**	**50**	**100**	**150**
Demonstrated Power, W_e [β]	6-34	26-54	45-150	60-300
Demonstrated Thermal Efficiency, % [γ]	38-63	62-84	78-85	71-78
Estimated System Electrical Efficiency, % [α]	18-30	30-40	37-41	34-37
Estimated Fuel Specific Energy, Whr/kg [δ]	1000 - 1680	1680-2240	2070 - 2300	1900-2070
Mass, g	65	105	155	245
Volume, cm^3	11	19	28	67
Power Density at Design Power, W/L [ε]	1750	2680	3650	2240
Specific Power at Design Power, W/kg [ε]	300	470	650	470

[α] Based on fuel cell having 60% conversion efficiency and 80% hydrogen utilization
[β] Performance values are reported for methanol conversion > 95%

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Catalysts and Reformers

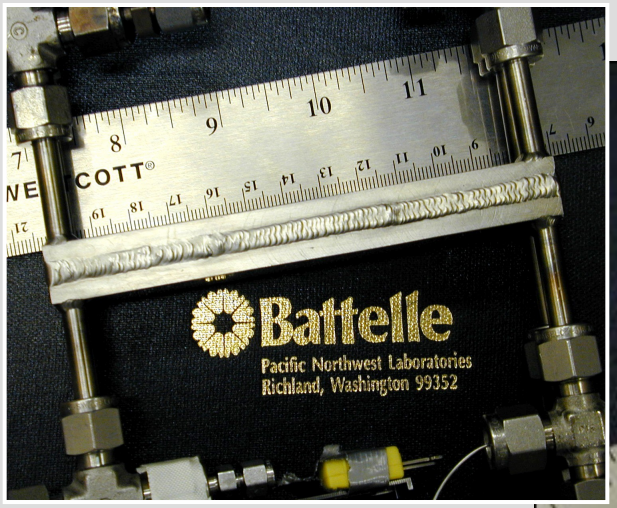
- Battelle's reforming catalysts
  - Highly active and selective
    - Low CO content at high temperature and high throughput
  - Total time on stream > 300 hrs (non-continuous)
  - Thermal cycles > 60
  - Air tolerant at moderate temperatures (<250 ℃)
    - Not pyrophoric
- Battelle's integrated steam reformer
  - Demonstrated thermal efficiencies up to 83%
  - Low CO concentration in reformate (<1 vol%)
    - Simplified gas cleanup

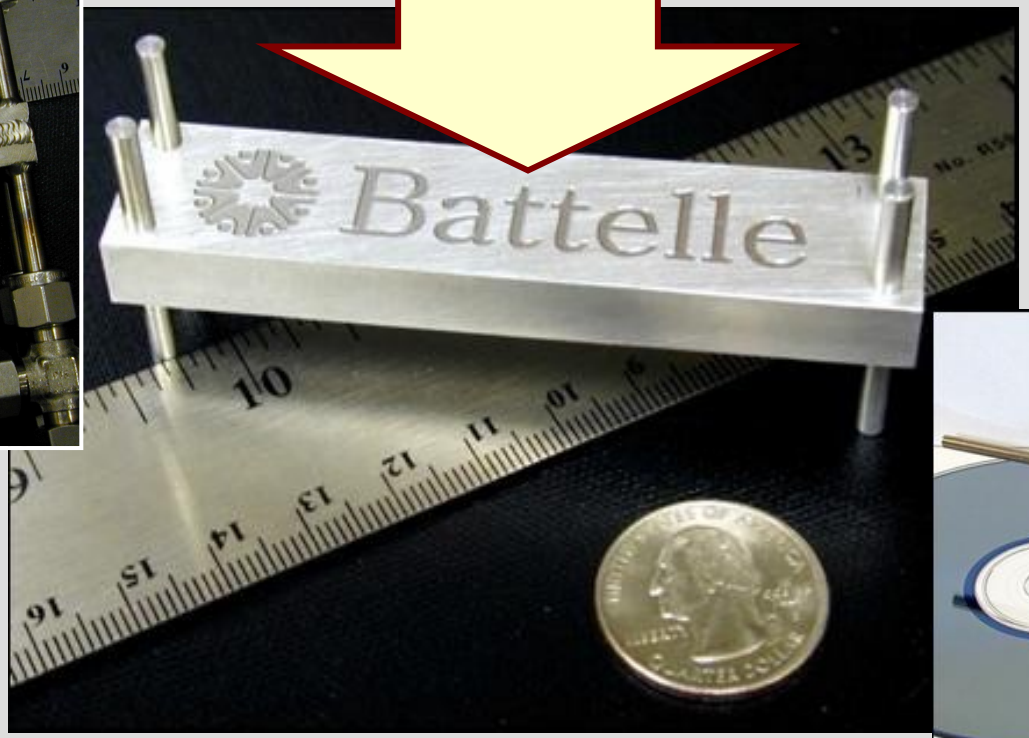
Fuel Processor Train

- **Integrated steam reformer plus CO methanation**
- Compact fuel processor development
  - 2000 status: concept
  - 2004 status: TRL 6 (fuel processor only)
- Enabling technology: microchannel reactors
- Specific enabling catalysts developed
  - Methanol steam reforming
  - Methanol, hydrogen, and hydrocarbon combustion
  - Selective CO methanation

Integrated Steam Reformers

- Methanol Steam Reformer
- Methanol Combustor
- Two Vaporizers
- Two Recuperators





System Overview

Fuel Processor
190-380 W_t
90-180 W_e

Controls and Peripherals
~25 W_e consumed

Fuel Cell
40-75 W_e

Power Electronics
~25 W_e consumed